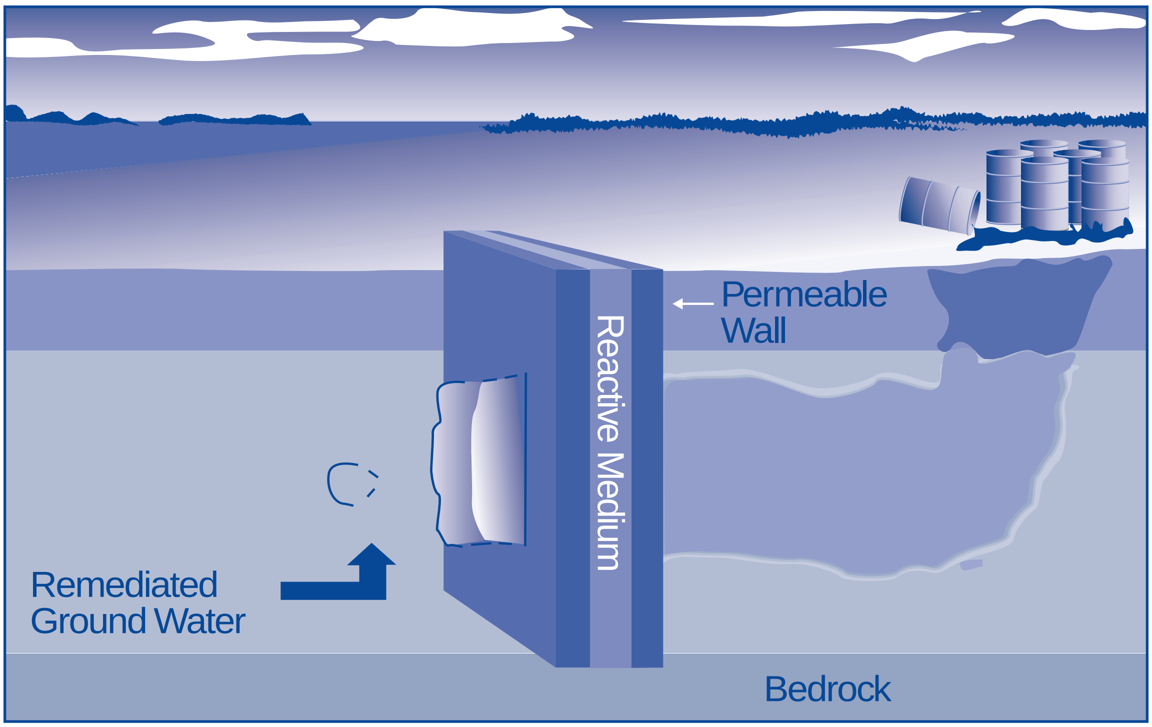
Technical/Regulatory Guidelines

Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Chlorinated Solvents



2nd Edition
December 1999

Prepared by
Interstate Technology and Regulatory Cooperation Work Group
Permeable Reactive Barriers Work Group

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Regulatory Guidance for Permeable Reactive Barriers Designed To Remediate Chlorinated Solvents**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Interstate Technology and Regulatory Cooperation Work Group,Washington,DC,20001**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**44**	

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at **www.itrcweb.org.**

DISCLAIMER

Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Chlorinated Solvents

2nd Edition
December 1999

Prepared by
Interstate Technology and Regulatory Cooperation Work Group
Permeable Reactive Barriers Work Team

ACKNOWLEDGMENTS

The members of the Interstate Technology and Regulatory Cooperation Work Group (ITRC), Permeable Reactive Barriers Work Team wish to acknowledge the individuals, organizations, and agencies that contributed to this regulatory guidance. We also wish to extend our thanks to those ITRC state representatives who took the time to review and comment on our drafts.

The Permeable Reactive Barriers Work Team effort, as part of the broader ITRC effort, is funded primarily by the United States Department of Energy. The United States Department of Defense and the United States Environmental Protection Agency have provided additional funding and support. Administrative support for grants is provided by the Environmental Research Institute of the States (ERIS), a nonprofit educational subsidiary of the Environmental Council of the States (ECOS). The Western Governors' Association (WGA) and the Southern States Energy Board (SSEB), who previously held secretariat duties for ITRC, remain involved.

The work team also wishes to recognize the individuals who were directly involved in this project, both in the initial stages of document development and the final stages of review and completion. We also wish to thank the organizations that made the expertise of these individuals available to the ITRC on this project. Appendix C lists members of the ITRC Permeable Reactive Barriers Work Team, as well as targeted reviewers, who contributed significant time and energy to this project.

The Remediation Technologies Development Forum (RTDF) provided review and consultation during many document revisions. We wish to thank the RTDF Permeable Barrier Walls Group and specifically the following individuals, who provided a significant amount of time and effort toward completion of the document:

Bob Puls	U.S. Environmental Protection Agency
Dale Schultz	DuPont
Arun Gavaskar	Battelle
Chuck Reeter	Naval Facilities Environmental Services Command

ITRC Permeable Reactive Barriers Team

Matt Turner
PRB Team Leader
New Jersey Dept. of Environmental Protection
401 E. State Street, 5th Floor
Trenton, NJ 08625
P 609-984-1742
F 609-633-1454
mturner@dep.state.nj.us

Jeff Breckenridge
U.S. Army Corps of Engineers
12565 West Center Road
Omaha, NE 68144
P 402-697-2577
F 402-697-2595
jeff.l.breckenridge@usace.army.mil

Alex Caruana
Colorado Dept. of Public Health and Environment
HMWMD-HWC-B2
4300 Cherry Creek Drive South
Denver, CO 80222-1530
P 303-692-3340
F 303-759-5355
alex.caruana@state.co.us

Jim Cummings
USEPA Technology Innovation Office
1235 Jefferson Davis Hwy
13th Floor – 5102-W
Arlington, VA 22202
P 703-603-7197
F 703-603-9135
cummings.james@epa.gov

Tom Douglas
Florida Dept. of Environmental Protection
2600 Blair Stone Road, Room 471D
MS 4540
Tallahassee, FL 32399
P 850-488-3935
F 850-922-4939
tom.douglas@dep.state.fl.us

Dib Goswami
Washington State Dept. of Ecology
1315 W. 4th Avenue
Kennewick, WA 99337
P 509-736-3015
F 509-736-3030
dgos461@ecy.wa.gov

Jim Harrington
New York Dept. of Environmental Conservation
Div. of Hazardous Waste Remediation
50 Wolf Road, Room 265
Albany, NY 12233-7010
P 518-457-0337
F 518-457-7743
jbharrin@gw.dec.state.ny.gov

David T. LaPusata
Massachusetts Dept. of Environmental Protection
205A Lowell Street
Wilmington, MA 01887
P 978-661-7600
davidlapusata@state.ma.us

Tim Larson
156 Big Buck Drive
Tallahassee, FL 32312
P 850-906-9737
F 850-906-9731
larssun@worldnet.att.net

Jeff Lockwood
Florida Dept. of Environmental Protection
2600 Blair Stone Road
MS-4535
Tallahassee, FL 32301
P 850-488-3935
F 850-922-4939
lockwood_j@dep.state.fl.us

Mark Malinowski
California Environmental Protection Agency
Dept. of Toxic Substances Control
301 Capital Mall, 3rd Floor
Sacramento, CA 95814-0806
P 916-322-4567
F 916-324-3107
mmalinow@hw1.cahwnet.gov

Brenda Pohlmann
Nevada Dept. of Environmental Protection
55 E. Washington, Suite 4300
Las Vegas, NV 89101
702-486-2857
702-486-2863

Dan Sogorka
PBW Team Project Support
Remedial Technologies, LLC
11417 Sunset Hills Road, Suite 230
Reston, VA 20190
P 703-481-9095
F 703-481-9125
dsogorka@remedial.com

Peter Strauss
Stakeholder Representative
PM Strauss and Associates
317 Rutledge Street
San Francisco, CA 94110
P 415-647-4404
F 415-824-1072
pstrauss@igc.apc.org

Anna Symington
Massachusetts Dept. of Environmental Protection
Bureau of Waste Site Cleanup
436 Dwight Street, 5th Floor
Springfield, MA 01103
P 413-784-1100, ext. 243
F 413-784-1149
anna.symington@state.ma.us

EXECUTIVE SUMMARY

The Permeable Reactive Barriers Team of the ITRC is composed of seven state regulatory agencies (New Jersey, Colorado, Florida, Massachusetts, Washington, New York, Nevada, and California) with participation from stakeholders, federal agencies, and members of the Remediation Technology Development Forum (RTDF). The Permeable Reactive Barriers Team has prepared this document to provide regulatory guidance for the implementation of permeable reactive barrier technology. The document is intended to serve as a regulatory guide for stakeholders, regulators, and technology implementors at sites where a permeable reactive barrier is being considered as a remedial alternative. The team has identified regulatory issues and recommended regulatory guidance for permeable reactive barriers wherever possible.

Because this is an evolving technology, this document is intended as a guide and should be updated periodically. Current research should always be reviewed when considering the guidelines outlined in this document. Users of this document are encouraged to study the references included in the document for further background and technical information on this technology. Recommended design guidance is contained in the reference "Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents," prepared for the Air Force Armstrong Laboratory/Environics Directorate by Battelle, February 1997. The Permeable Reactive Barriers Team participated in the development of this document.

This document focuses on treating chlorinated solvents using a funnel-and-gate application, but much of the guidance provided may also be applicable to continuous permeable reactive barrier applications. In addition, there are numerous variations in media, contaminants treated, and system designs that are not covered in this document. Portions of the guidance may have some relevance to alternative systems depending upon the application. The document also addresses site characterization, bench-scale testing, modeling, and waste disposal as they pertain to permeable reactive barrier applications. Sections on permitting, monitoring, maintenance and closure criteria, stakeholder concerns, and variances are also included to address potential regulatory and technical issues during project development.

Members of the team developed the draft document. Technical and regulatory issues were discussed during conference calls and breakout sessions at ITRC meetings, and consensus was reached whenever possible. The document was distributed for peer review, and comments were received from representatives of state and federal agencies, public stakeholders, industry, consultants, and vendors. Comments were discussed, evaluated, and incorporated into the document as appropriate. This document is now under review by ITRC state agencies to determine the degree of concurrence on the technical and regulatory guidelines contained within.

The 2nd edition updates the version of this document released in December 1997.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

REGULATORY GUIDANCE FOR PERMEABLE REACTIVE BARRIERS DESIGNED TO REMEDIATE CHLORINATED SOLVENTS

1.0 INTRODUCTION

As indicated by the title, this document focuses on providing regulatory guidance for permeable reactive barriers designed to remediate chlorinated solvents. Terms such as reactive barrier, funnel and gate, in situ reductive dechlorination, and metal-enhanced reductive dehalogenation have been used in the research and industrial communities to describe this technology. Although this guidance focuses on treating chlorinated solvents using a funnel-and-gate application, much of the guidance provided might also be applicable to continuous permeable reactive barrier applications. Although there are variations in media, contaminants treated, and system designs that are not covered in this document, portions of this guidance may have relevance to alternative systems depending upon the application.

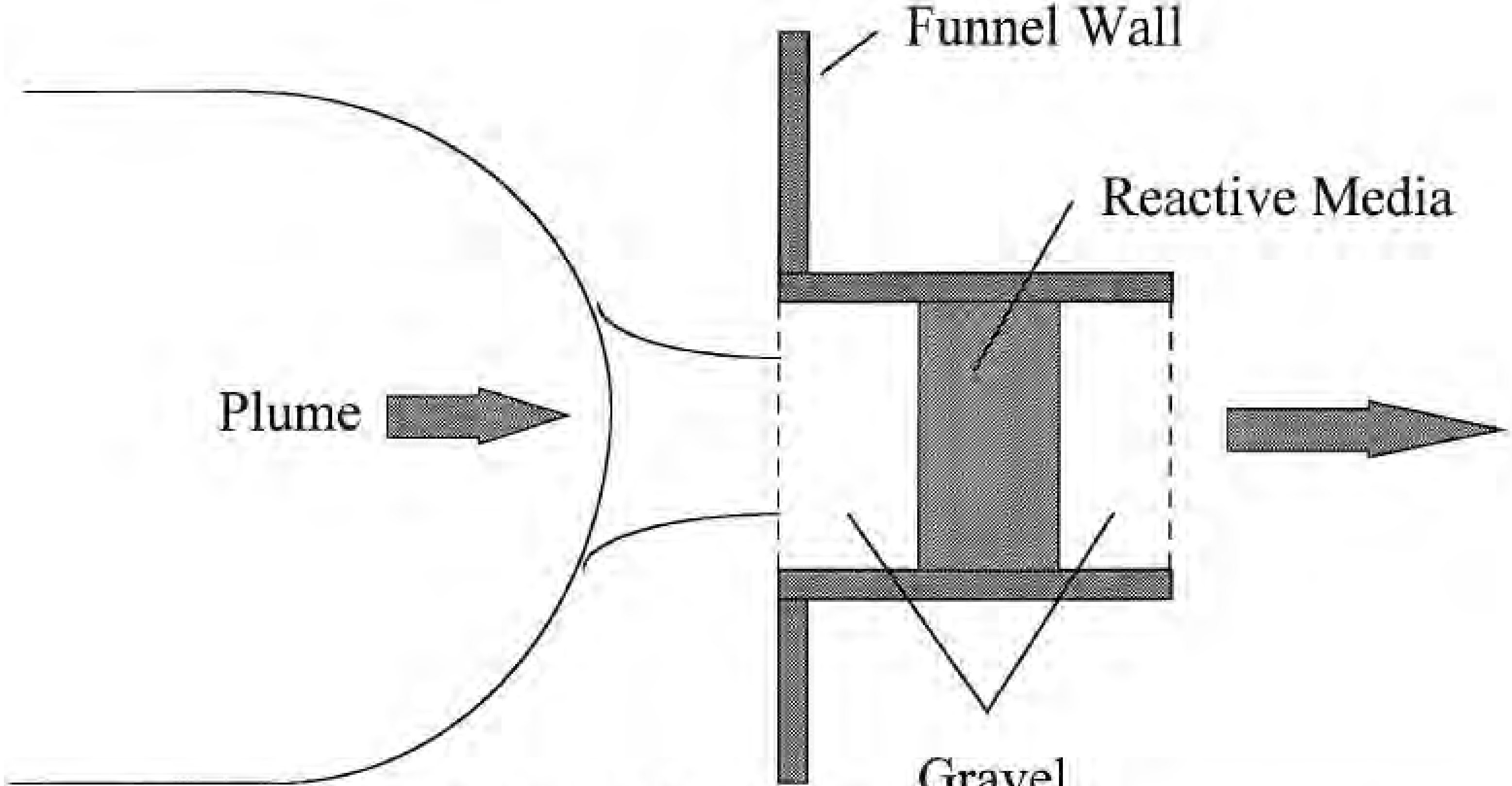
The economic benefits of permeable reactive barriers have been driving the interest in the technology. At chlorinated solvent–contaminated sites, a passive technology that requires almost no annual energy or labor input (except for site monitoring) has obvious advantages over conventional groundwater treatment systems. A cost-benefit approach should be used to evaluate the economic feasibility of a permeable reactive barrier at a given site. Potential users should contact EnviroMetal Technologies, Inc. (519-824-0432), 42 Arrow Road, Guelph, Ontario Canada, 41K 1S6, the patent holder of the technology, for information regarding system installation.

Potential variations on the permeable reactive barrier technology include
- Ex- and in-situ treatment vessels,
- Nested wells containing reactive media,
- Pressurized jetting of reactive media into aquifer sediments,
- Vertical hydrofracturing,
- Interception trenches routed to reactive media,
- Biological barriers,
- In-situ reduction of naturally occurring iron in aquifer sediments to zero-valent iron using injected reagents.

Alternative media selections include
- Bimetallic media,
- Palladized iron,
- Colloidal iron,
- Dithionite,
- Oxygen release compound.

To provide consistency, Figure 1-1 on the following page illustrates the terms used in this document.

Figure 1-1 Permeable Reactive Barrier



Permeable Reactive Barrier refers to the entire system
In-Situ Treatment Zone (ISTZ) refers to the permeable treatment area comprised of the media and gravel
Reactive Media refers to the media (i.e., iron) portion of the ISTZ
Funnel Wall refers to the impermeable portion of the system

2.0 SITE CHARACTERIZATION

2.1 Data Requirements

The data requirements for characterization can be divided into two main categories:

1) Initial site characterization

2) Data requirements during and after emplacement of the treatment barrier

A brief description of the major data requirements for the initial phase activities is given below. Since our emphasis is on requirements for the barrier and the determination of its success as a remedial alternative, a detailed description of data needs during and after emplacement is presented in Table 2-1.

2.1.1 Initial Site Characterization

Measurement of presystem emplacement baseline conditions should be initiated and established such that postsystem-emplacement effects on concentrations, distributions, and aquifer levels can be determined. This should include, but is not limited to, the following information.

Geological Data
Site-specific geological data incorporating details on physical setting, stratigraphy, aquifer heterogeneity, structure, and sedimentology should be provided based on a survey of existing literature, remedial investigations, and feasibility studies. Site-specific data from activities such as drilling and sampling must be included to obtain essential information necessary for system design.

Contaminant Plume(s)
Information regarding the contaminant plume(s) and source should be provided. The nature and concentration of all contaminants, their vertical and lateral distributions, and all pertinent degradation characteristics should be included (i.e., degradation by metallic media, natural attenuation, biodegradability, etc.). Of particular relevance to permeable reactive barriers are specific areas of high concentrations and the presence of any contaminants that may not be susceptible to dechlorination, such as 1,2 dichloroethane (DCA).

Hydrogeologic Data
All relevant hydrogeologic and aquifer characteristics should be identified. These may include groundwater levels, temperatures, pH, flow velocity, porosity, hydraulic conductivity, site heterogeneity, depth to aquitard, and aquitard continuity, thickness, and competence. All major controlling influences on groundwater flow should be defined (e.g., bedrock, production wells, tidal and seasonal influences, surface features, infiltration). Information from aquifer tests should be synthesized into a conceptual site model.

Geochemical Data
Both organic and inorganic geochemical information along with groundwater chemistry should be evaluated for their potential to affect the functionality of the treatment barrier. The nature and concentrations of chlorinated solvents should be defined to select the amount and type of treatment media to be used.

Microbiologic Data
Microbial data may be needed on a site-specific basis. The role of microbes relative to permeable reactive barriers is currently under review. More information on microbiological data requirements will be determined through ongoing research.

2.1.2 Data Requirements during and after Placement of the Barrier

The majority of data vital to the success of the permeable reactive barrier are obtained during the remedial investigation and feasibility study. Details of data collection are included in Tables 2-1, 2-2, and 2-3. The primary objectives of data collection are to

- Evaluate performance of the reactive media in destroying chlorinated solvents relative to the laboratory bench and column testing data using samples of site-specific contaminated groundwater. (State-specific guidelines and regulations should be adhered to.)
- Define hydrogeologic characteristics of the permeable reactive barrier to determine initial and long-term performance.
- Determine constructability of the ISTZ relative to the reactive media.
- Evaluate costs associated with design, installation, operation, maintenance, and monitoring. This information can also be used for cost comparisons with other remedial technologies. The economic evaluation is crucial for CERCLA/Superfund sites in particular. The Federal Remediation Technology Roundtable offers guidance for the collection of these data.

Table 2-1 identifies activities recommended to achieve the data requirements. This table addresses the primary objectives, detailed sub-objectives, data analysis methods, and timing of the activities. Table 2-2 identifies data gathering activities to support the data requirements. This table addresses the activity, the main purpose, and the data provided.

2.2 Analytical Methods

EPA-approved methodologies should be employed for compliance samples. Volatile organic compounds (VOCs) in groundwater sampling can be analyzed by USEPA SW-846 (3rd Edition) Methods 8240 or 8260a, as well as USEPA Method 624. GC methods may be substituted for GC/MS methods after the identities of compounds of interest, including breakdown products, have been established. These GC methods may include USEPA SW-846 Methods 8015a, 8020a, and 8021a.

Inorganic analytes should be measured by EPA-approved methods. These methods provide valuable information on the chemistry of the local groundwater and its effects on the performance of the reactive media. State-specific protocols should be reviewed to determine whether filtered or unfiltered samples should be collected.

Table 2-3 identifies the field and laboratory parameters that should be monitored. The table addresses analyte or parameter, analysis method, sample volume, storage container, preservation method, and sample holding time.

Table 2-1 Activities Suggested to Achieve Objectives

Primary Objective	Detailed Sub-objective	Data Analysis Method	Timing of Activity
Evaluate performance of reactive media	Evaluate reactivity of media. Determine reaction rate and compliance with state-specific cleanup standards. Identify the potential need for alternative cleanup standards or technologies if compounds cannot be treated to compliance levels.	Batch and column experiments.	Before construction and during system operation
Define hydrogeologic characteristics	Evaluate impact of permeable reactive barrier on aquifer and ensure capture of contaminants.	Compare pre- and postemplacement aquifer hydrologic tests and water quality information across ISTZ and entire PRB.	Design, emplacement and system operation
	Hydrologic performance evaluation including contaminant degradation capability, system longevity (i.e., compaction, plugging, precipitate formation and migration, by-product formation, etc.) and subsurface characteristics.	Compare postemplacement and final aquifer hydrologic tests across the ISTZ using site investigation techniques. Evaluate precipitate formation from geochemical data and modeling.	Bench-scale longevity testing, feasibility, design, and system operation
	Evaluate groundwater gradient.	Collection of water levels.	Before construction and during system operation
Determine constructability of the ISTZ*	Evaluate the ability to achieve design depth and width.	Observe, boreholes, cone penetrometer testing.	Before construction
	Evaluate ability to emplace reactive media without abrading, crushing, or mixing with fines from excavated and surrounding materials.	Observe. Review proposed construction method.	Before and during construction
	Evaluate the ability of the method to control and provide QA of design parameters.	Review design package.	Before and during construction
	Identify operational issues in the following categories: environmental, cultural, health and safety.	Review proposed design package/construction method.	Before and during construction
	Identify any other construction issues and ideas for improvement.	Observe.	During construction
Evaluate Costs	Determination of design and installation costs.	Obtain quotes and cost estimates.	During procurement process, feasibility and design
	Determine any operation/maintenance and monitoring costs.	Obtain quotes and cost estimation tools.	Feasibility and design
	Develop information for cost comparisons with other remedies.	Obtain quotes and cost estimation tools, perform Benefit/Cost Analysis.	Feasibility and design
	Obtain information to document final Cost & Performance.	Federal Remediation Technology Roundtable	Throughout project

*ISTZ (In-situ treatment zone)

Table 2-2 Data Gathering Activities to Support Objectives

	Activity	Main Purpose	Data Provided
A	Up and downgradient monitoring well installation.	Hydrologic testing and characterization. Water quality monitoring.	CS delineation, lithology, water level monitoring to determine groundwater flow vectors.
		Determine flow direction in and around treatment zone.	Water level measurements for sampling and tracer tests.
B	CS* and water quality baseline.	Establish trends and baseline dissolved phase CS concentrations in monitoring wells.	Groundwater concentration of CS, other contaminants of concern, pH, conductivity, Eh, DO, and other ions in solution (see Table 2-3).
C	Pre-emplacement hydrologic tests, water levels, hydraulic conductivity, transmissivity monitoring, and geologic conceptual site model.	Determine geologic properties of site prior to treatment zone installation.	Hydrologic conductivity, storativity, vertical anisotropy, transmissivity, location and geologic nature of confining unit(s).
D	Batch and column experiments.	Determine characteristics of reactive media.	Reactions and rates of reactions, by-products, effects on water quality, reactive media thickness, hydraulic performance, stability, cost analysis.
E	Modeling and measurement of the aquifer.	Determine permeable reactive barrier configuration and placement.	Prediction of plume capture and effect of system on aquifer characteristics. Transmissivity and flow determinations and predictions.

*CS (Chlorinated Solvents)

Table 2-3 Field and Laboratory Parameters

Analyte or Parameter	Recommended Analysis Method[a]	Sample Volume[b]	Storage Container	Sample Preservation	Sample Holding Time
Field Parameters					
Water Level	In-hole Probe	None	None	None	None
pH	In-hole Probe or Flow-thru Cell	None	None	None	None
Groundwater Temperature	In-hole Probe	None	None	None	None
Redox Potential	Flow-thru Cell	None	None	None	None
Dissolved Oxygen	Flow-thru Cell	None	None	None	None
Specific Conductance	Field Instrument	None	None	None	None
Turbidity	Field Instrument	None	None	None	None
Salinity	Field Instrument	None	None	None	None
Organic Analytes					
Volatile Organic Compounds (VOCs)[c]	EPA 8240	40 mL	Glass VOA vial	4ºC, pH <2 or No pH adjust.	14d 7d
	EPA 8260a (modified)	40 mL	Glass VOA vial	4ºC, pH <2 or No pH adjust.	14d 7d
	EPA 624	40 mL	Glass VOA vial	4ºC, pH <2 or No pH adjust.	14d 7d
Inorganic Analytes					
Metals[d]: K, Na, Ca, Mg, Fe, Al, Mn, Ba	200.7	100mL	Polyethylene	4ºC, pH<2, (HNO_3)	180d
Anions: SO_4, Cl, Br, F	300.0	100mL	Polyethylene	4ºC	28d
NO_3	300.0	100mL	Polyethylene	4ºC	48h
Alkalinity	310.1	100mL	Polyethylene	4ºC	14d
Other					
TDS	160.2	100 mL	Glass, Plastic	4ºC	7d
TSS	160.1	100 mL	Glass, Plastic	4ºC	7d
TOC	415.1	40 mL	Glass	4ºC, pH <2 (H_2SO_4)	28d
DOC	415.1	40 mL	Glass	4ºC, pH <2 (H_2SO_4)	28d

d - days h - hours
[a] - If <1.0 mg/L, use photometric field kit for analysis.
[b] - See Section 6.4 of this report, "Sampling," for variances in sample volumes.
[c] - GC methods may be substituted once identity of compounds and breakdown products are verified.
[d] - Other metal analytes that are characteristic of the media should be included.

For a list of applicable acronyms and abbreviations, see Appendix A.

2.3 QA / QC

During site characterization and monitoring, state-specific groundwater quality objectives should be identified and used to determine the appropriate analytical methods based upon the goals and cleanup standards applicable to the site. All QA/QC required by the analytical method should be completed. At a minimum, lab QA/QC summary documentation (including nonconformance summary report and chain of custody) should be submitted with analytical results. QA/QC deliverables as specified by the analytical method should be maintained and made available upon request for at least three years. QA/QC requirements and reporting requirements should be determined by project-specific data quality objectives. Ultimate responsibility for QA/QC documentation belongs with the responsible party of a site or the vendor conducting a demonstration. However, the responsible party may contract with another entity, such as an analytical laboratory, to house the actual QA/QC data. In addition, all state-specific reporting requirements should be adhered to.

QA/QC may also be applied to the construction of permeable and impermeable barriers. Construction activities may consist of the following items:

- Impermeable barrier placement,
- Placement and sealing of sheet pilings,
- Trenching and slurry placement,
- Mixture of slurry and backfill,
- Submittal of as-built diagrams.

Additional considerations and guidance for various types of barriers can be found in Battelle's "Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents" (Battelle, 1997).

2.4 Waste Disposal

During the investigation of the site, investigation-derived waste may be generated. Any contaminated soil should be classified in accordance with state and federal Hazardous Waste Regulations prior to disposal. The classification of the soil will determine the disposal method. State-specific requirements should be followed for sample parameters and frequency to ensure the soil is properly classified prior to disposal. In cases where the generated soil is classified as hazardous, state and/or federal waste regulations will dictate the disposal method. State-specific requirements may also regulate the disposal of nonhazardous waste if the material is contaminated.

Water may be generated during well installation and sampling. Any contaminated water should be disposed of in accordance with state-specific requirements. Several options may apply; water can be disposed of at a permitted off-site commercial facility, a publicly owned treatment works, or on site in accordance with NPDES regulations.

3.0 BENCH-SCALE TESTING FOR PERMEABLE REACTIVE BARRIER DESIGN

Following site characterization, bench-scale treatability testing is usually performed to aid in permeable reactive barrier design. The primary objective of bench-scale testing is to estimate the half-life of the degradation reaction. Other objectives of bench-scale testing include

- Screening and selecting a suitable reactive media (iron, zeolites, etc.) for the ISTZ,
- Determining the flowthrough thickness of the ISTZ,
- Determining byproduct and water quality issues,
- Estimating costs,
- Determining potential precipitation/plugging of reactive media.

Bench-scale tests can be conducted in batch or column (continuous) mode. Batch testing can be useful as an initial screening tool to evaluate half-lives, different reactive media, and degradation of recalcitrant contaminants.

Column testing provides more reliable reaction rate parameters than batch testing. Column testing provides information from dynamic flow conditions. Sampling ports placed along the column provide more information on changing contaminant and inorganic concentrations over distance than can be determined by batch sampling. High groundwater velocities may require use of longer columns or multiple columns in series.

Various types of water can be used for bench-scale testing:
- Deionized water spiked with contaminants of concern,
- Clean groundwater from the site spiked with contaminant(s) of concern,
- Contaminated groundwater from the site.

Groundwater from the site (clean or contaminated) should be used during bench-scale tests so that water chemistry effects on the treatment media can be evaluated. If clean water from the site is used, ensure the general water chemistry is similar to that of the targeted contaminated water.

4.0 MODELING

4.1 Conceptual Site Model

The conceptual site model is developed based on site-specific and modeling data and should depict site conditions (e.g., contaminant migration pathways, subsurface geology, groundwater flow, etc.). The conceptual site model should be updated as data is collected and the hydrogeologic models are refined. Regardless of the type of model selected, a conceptual model of the aquifer will need to be developed. Information useful in developing the site conceptual model includes
- Sketches, cross sections, and block diagrams,
- Flow nets in map view and cross-section,
- Aquifer geometry and distribution of geologic materials both laterally and vertically,
- Nature of the underlying bedrock,

- Description of lateral aquifer boundaries,
- Discussion of major withdrawals or recharge to the aquifer,
- Leakage from overlying bodies of water, wetlands, or underlying aquifers,
- The nature of any confining units that might be present,
- The gaining or losing nature of any streams or rivers within or adjacent to the aquifer,
- Horizontal and vertical hydraulic gradients,
- Hydraulic conductivity and storativity of the different geologic materials in the aquifer,
- Distribution of natural recharge across the aquifer,
- Data presentation and analysis of redox potential, alkalinity, and other geochemical parameters that could affect performance.

The more complex the site, the greater the level of effort required to evaluate the hydrogeology and the more detailed the conceptual model becomes.

4.2 Hydrogeologic Models

Hydrogeologic models include groundwater flow, contaminant transport, and geochemistry models. Hydrogeologic modeling is used to aid in designing the permeable reactive barrier and in developing a conceptual site model. As data is collected and incorporated, the conceptual site model becomes more refined.

Hydrogeologic modeling is necessary for the following reasons:

- Determine an approximate location and configuration of the permeable reactive barrier with respect to groundwater flow, plume movement, and flow velocity through the ISTZ,
- Determine the dimensions of the permeable reactive barrier and ISTZ,
- Estimate hydraulic capture zone,
- Determine location and sample frequency of monitoring wells,
- Evaluate the hydraulic effects of potential losses in porosity, flow bypass, underflow, overflow, or flow across aquifers.

A number of hydrogeologic models are available commercially[1]. Some states may have specific requirements to use a particular model. Flow and transport models range from simple 2-D models to more complex 3-D models. Model selection should be based on site-specific information and established project objectives. The model must be capable of solving for transport and transformation processes found at the site. At some sites, the processes may be relatively simple and a basic model will provide adequate results. Complex sites may require a more complex model.

Qualitative geochemical calculations and geochemical modeling can be used to evaluate potential precipitation impacts to the reactive media. Geochemical modeling attempts to interpret and predict groundwater chemistry based on assumed chemical reactions. Geochemical methods can be used to

[1]Examples include MODFLOW (McDonald and Harbaugh, 1988), MODPATH (Pollock, 1989), FLONET (Guiguer et al, 1992) and FLOWPATH (Waterloo Hydrogeologic, Inc., 1996). Examples of Geochemical models include EQ3, PHREEQE, and PHREEQC.

evaluate pH and alkalinity changes from installation of the permeable reactive barrier treatment media that could lead to calcium and magnesium carbonate precipitation. In the absence of geochemical modeling, arithmetic comparisons of calcium and magnesium before and after the reactive media can provide information on potential reactions.

Modeling requires an in-depth understanding of groundwater flow and begins with collection of comprehensive data on the aquifer being studied. If aquifer data is limited and does not contain significant information with which to compare and verify the response of a model, it may lead to erroneous conclusions. With larger sites, the model should be periodically updated as new field data is obtained. The primary objective of hydrogeologic modeling is to simulate site-specific processes with a high degree of confidence using an adequate number of representative data points.

Modeling results should reflect conditions provided from the actual monitoring results at the site. Whenever a model is used, it is important to ensure that the model is calibrated and continually validated.

Calibration is an iterative process of adjusting model parameters (i.e., hydraulic conductivity, transmissivity, dispersivity, and contaminant concentrations) so the model adequately approximates the groundwater system. The model parameters should be compared to the field data. Ultimately, the ability of the model to simulate the real system is based on the quality and quantity of site-specific data provided.

Validation is the process of comparing the calibrated model to an independent data set for the groundwater regime. Failure of a model to approximate a validation data set indicates a need for recalibration of the model.

Integration of monitoring and modeling results should provide confidence that adequate monitoring exists. When a model has been selected, calibrated, and validated, it may be used to simulate future groundwater flow, contaminant distribution, and water chemistry conditions.

Use of a groundwater model allows for evaluation of different designs, site parameters, and performance scenarios to aid in selecting an appropriate design for the site. Models can also be used to optimize well placement and sample frequency for evaluation of the permeable reactive barrier. Groundwater modeling results and model prediction scenarios should be presented in a clear graphical and narrative form. The presentation should include

- A statement of purpose and objectives of the selected model;
- A conceptual presentation of the selected model, incorporating information from the conceptual model; rationale as to why the model was used; and a discussion of any deficiencies or limitations of the model;
- An explanation of data collection and analysis and the level of confidence in the resulting parameter identification;
- A description of the selected model (software) and justification for its selection;
- A description of the hydraulic and transport values and conditions assigned throughout the model and justification for such;
- A description of the model calibration, results of the final calibration run, and any departures from

the calibration targets;
- Results of the model validation;
- A determination of what parameters of the model have the greatest influence on the model results (i.e., a sensitivity analysis);
- A description of pre- and postprocessing of model input data;
- A presentation of the model output of all predictive scenarios, including the effects of model sensitivity and uncertainty on the predicted results;
- A discussion of how well the model represents the physical and chemical processes of the environment being simulated, both in technical and nontechnical terms;
- Model records should be maintained to provide the following:
  - The version of the source code selected,
  - Input parameters, boundary, and initial conditions,
  - The final calibration run (input and output files),
  - All predictive runs (input and output files).

5.0 PERMITTING

Relatively few permitting issues are associated with permeable reactive barriers. Major issues that may arise during installation are the National Pollution Discharge Elimination System (NPDES) permits, Underground Injection Control (UIC) requirements, and Air Quality Permitting considerations, all of which are addressed below. In addition to these major considerations, a thorough review of all permitting issues should be conducted on a site-specific basis. State-specific regulations and municipal requirements should be reviewed to ensure compliance. For instance, many states require a permit for the installation of a well. In some cases, the location of the site may trigger the need for permits. An example is an installation close to or within a wetlands. In addition to permits, states may have alternative approval processes, including submittal of a work plan for state review and/or approval of a corrective action plan under RCRA.

A UIC permit will typically not be required for the installation of a permeable reactive barrier. However, monitoring for leachability of the reactive media (Fe, etc.) in downgradient water quality should be a requirement of the site-specific monitoring plan in most instances. The only consideration in determining the applicability of a UIC permit is the installation technique. When the installation involves excavation and the construction of a barrier, a UIC permit will not be required. Furthermore, similar techniques of emplacement (caisson, mandrel, continuous trencher, etc.) will not trigger the need for a UIC permit. An installation of this type will not necessarily meet the definition of a well under UIC regulations. Furthermore, when the reactive media is emplaced in the ground in solid form, a UIC permit is not needed. However, if the reactive media is installed by a high-pressure jetting technique or by vertical hydraulic fracturing, a permit may, in some circumstances, be required. The need for a permit under these conditions will be a state-by-state determination. A review of the pertinent regulations should be conducted during initial design stages of the project.

A NPDES permit may be required to dispose of excess water generated during installation. The need for a NPDES permit is addressed in Section 7.0, Disposal of Waste During Barrier Placement.

Air permits will not typically be required for the release of VOCs during the installation of a permeable reactive barrier. These barriers are usually installed downgradient of the contamination source in an area where aqueous contamination is the major concern. The concentrations of organic compounds released under these conditions are typically below levels that would require permitting. However, an evaluation is usually required to determine the need for health and safety monitoring and to ensure that there are no off-site excursions of fugitive emissions.

6.0 MONITORING

The major objective of groundwater monitoring is to ascertain compliance with state standards. The following sections provide general guidance that is applicable across the states. It may be necessary to identify alternative concentration limits (ACLs) or to incorporate supplemental technologies to address contaminants that may be above criteria at a particular site.

6.1 Monitoring Well Construction

6.1.1 Aquifer Wells

State-specific requirements should be followed for the installation of monitoring wells that are intended to monitor groundwater quality and/or levels. Many states have well installation standards or guidelines or require a permit for the installation of a well. The permit process may require an application and a fee.

6.1.2 Wells within the Permeable Reactive Barrier

The design of monitoring wells installed within the ISTZ will differ significantly from the typical well construction criteria. These wells will not incorporate a sand pack or grouting into the design, as is typically required in state installation requirements. ISTZ wells will be surrounded by the backfilled reactive media and can be finished at the surface similar to aquifer wells. The monitoring wells are usually constructed using smaller diameter (1 or 2 inch) PVC casing. Smaller diameters are preferred to limit the purge volume. The diameter must be sufficient to accommodate sampling equipment. In the case of a funnel-and-gate configuration, ISTZ wells can be suspended in the excavation prior to backfilling. These wells can be supported by a metal framework that is removed during backfilling of the ISTZ. For other configurations, wells may be pushed into the ISTZ. The wells may have a long screen or may be positioned in clusters with small screen intervals for sampling discrete areas and various depths.

6.2 Monitoring Well Placement

Groundwater modeling should be used as a tool for the determination of monitoring well locations. Groundwater monitoring wells should be installed both upgradient and downgradient (on both sides) of the permeable reactive barrier. At a minimum, selection of monitoring well screen intervals and

lengths should consider

- Site geology,
- Aquifer thickness,
- Aquifer flow (horizontal and vertical) characteristics,
- Presence of multiple aquifers,
- Nature of contamination,
- Construction details of the permeable reactive barrier,
- Conformance with state guidance and regulations.

Installation of monitoring well clusters (multiple discretely screened wells within a single boring) may be appropriate if more than one aquifer is present.

Monitoring wells should also be placed within the ISTZ and at the ends of the funnel wall to ensure that contaminants are not migrating through or around the permeable reactive barrier (refer to Section 6.5 of this report). While an aquifer may be homogeneous, the installation of multilevel or cluster wells is recommended within the ISTZ, since it has the potential for developing heterogeneities due to compaction of the iron fines and the development of corrosion products or precipitates within the ISTZ pore space. It is important that some wells be screened at the bottom of the excavation of the ISTZ to monitor for potential contaminant migration beneath the barrier. In addition, when employing a funnel-and-gate system or variation thereof, monitoring wells should be installed near the walls of the ISTZ, as the groundwater velocity tends to be greater at these points. Note that when assessing optimum well locations, contaminant breakthrough may very well occur along the ISTZ walls and not necessarily within the middle of the ISTZ. Refer to Section 6.8 and Figures 6-1 and 6-2, which graphically depict the monitoring well placement concepts outlined in this section.

The appropriate number of monitoring wells will be determined by the size and geometry of the contaminant plume, the size of the permeable reactive barrier, groundwater flow rate, and the heterogeneities of the surrounding media and the ISTZ. It is important when considering the number and location of wells that all aspects of the contaminant plume are characterized and conceptually understood. The number and location of wells must be sufficient to quantify reductions in contaminant levels over time as a measure of performance of the permeable reactive barrier.

6.3 Analytical Parameters and Methods

EPA methodologies should be employed for analysis. Section 2.2 of this report lists methods, preservatives, and holding times. Table 2-3 identifies the field and laboratory parameters. The table addresses analyte or parameter, analysis method, sample volume, storage container, sample preservation, and sample holding time.

6.4 Sampling

Sampling of wells close to the ISTZ or within the ISTZ requires special considerations in order to obtain a representative sample. Typical well purging methods and volumes will not apply to these wells. To obtain a representative groundwater sample, the residence time of the groundwater within the ISTZ must not change. The volume of groundwater removed and the rate at which it is removed

must not change residence time within the ISTZ. A very low-flow purge rate and a small volume of groundwater (significantly less than three well volumes) should be purged to ensure that the groundwater being sampled has had sufficient time to react within the ISTZ. Alternatives for sampling include use of a low-flow sampling procedure, dedicated submersible pumps, and packers or other specialized sampling devices for reducing the purge and sample volume. There are currently no guidelines on the amount or rate at which groundwater should be purged. This is an issue that must be determined on a case-by-case basis. Keep in mind, however, that a slower and smaller purge will have the least effect on residence time, thus providing a more representative sample of ISTZ performance.

Conventional purging and sampling can be used on monitoring wells positioned away from the ISTZ, provided the purging and sampling will not influence groundwater flow through the ISTZ.

6.5 Monitoring Frequency

Groundwater flow velocity is a key component in designing and establishing a monitoring schedule. Rates of groundwater flow can be quite variable for permeable reactive barriers. If the groundwater flow rate is high, a more frequent schedule is applicable as there are more rapid changes occurring; if the groundwater flow rate is low, a less frequent schedule may be applicable as changes are occurring less rapidly within the aquifer. If a permeable reactive barrier is built downgradient of a plume, it may take weeks or months for the plume to reach the barrier, especially when groundwater flow velocities are low. Measuring organic parameters before the plume reaches the barrier may be unnecessary. Table 6-1 provides monitoring frequency guidance for permeable reactive barriers; as always, site-specific considerations and professional judgement should be used to determine frequencies and parameters.

In general, during the first quarter after the plume reaches the barrier, monthly sampling of field parameters and organic and inorganic constituents should be performed on wells within and close to the ISTZ. These data will help evaluate the effect of the permeable reactive barrier installation on the surrounding aquifer. It should be noted that monitoring during the first quarter will not be representative of the performance of the permeable reactive barrier after equilibrium is reached. Disturbances caused by the installation process have been known to create changes in the concentration of groundwater contaminants. These changes should be monitored and recorded until this process is better understood.

Initial placement of a permeable reactive barrier has been reported to temporarily increase the levels of groundwater contaminants in some instances. The increase may be due to desorption of contamination from the installation technique, changes in groundwater flow velocity, or some unknown phenomenon. The potential exists for the placement of a permeable reactive barrier to create a vector of groundwater contamination that may affect noncontaminated wells. These scenarios are transitory effects from the installation process. The overall performance of the permeable reactive barrier system should not be affected over a longer time period. In some instances, enhanced performance of the permeable reactive barrier has been reported during the first few months following system startup, after which performance tends to reach equilibrium. As more experience with permeable reactive barriers is gained, the initial monitoring program may be subject to modification.

After the first quarter, samples for chemical analyses should be collected on a quarterly basis from the wells within the ISTZ and selected upgradient and downgradient wells. Wells along and at the ends of the funnel wall(s) should also be sampled quarterly to evaluate movement under and around the wall. In establishing monitoring requirements for the first year, evaluation of modeling data should be performed to identify the most useful data points. Monitoring should be designed to evaluate the sensitivities of a variety of parameters over the first year of operation at a site. A strategy may then be developed to reevaluate the monitoring parameters, locations, and analytical data on a continuing basis to ensure that the sampling locations and parameters are appropriate. This may result in the elimination of redundant monitoring points or certain parameters at specific sampling locations from the quarterly monitoring plan.

Continual adjustments based upon an increased understanding of the performance of the system and recalibration of the model should drive decisions on establishing the frequency and locations of monitoring. Based on the long-term performance of the barrier and a reevaluation of the monitoring plan and operational data, a reduction from the quarterly sampling schedule may be instituted after the first or second year of operation.

Gathering groundwater level data is a relatively inexpensive analysis, which can provide a great deal of information regarding the performance of the system. During the first quarter, groundwater level data should be collected on a weekly basis for all wells associated with the permeable reactive barrier to determine and observe any changes in the components of groundwater flow after permeable reactive barrier installation. Measurement of groundwater levels during the first and second year of operation should be conducted on a quarterly basis, during which evaluation of the data will indicate where the frequency can be reduced or where monitoring wells can be eliminated from the monitoring program. Groundwater level data should be collected even if the plume has not yet reached the barrier to ensure that equilibrium is being reached and that no damming of the aquifer is occurring. This schedule of groundwater monitoring takes into account seasonal variations in groundwater levels.

Table 6-1 Permeable Reactive Barrier Monitoring Frequency

Parameter	Frequency
A - First Quarter After Installation	
Field Parameters	Monthly
Organic Analytes	Monthly
Inorganic Analytes	Monthly
Groundwater Levels	Weekly (until equilibrium is reached)
B - Initial Monitoring Program (1 - 2 years)	
Field Parameters	Quarterly
Organic Analytes	Quarterly
Inorganic Analytes	Quarterly
Groundwater Levels	Monthly, then to be determined
C – Long-Term Monitoring	
Field Parameters	Quarterly (may be reduced based upon operational stability)
Organic Analytes	
Inorganic Analytes	
Groundwater Levels	
D – Postclosure Monitoring	
Inorganic Parameters (Fe and other leachable constituents)	To be determined based upon data collected during operation

* Refer to Table 2-3 for analysis method.
** Groundwater levels should be measured to 0.01 feet.

6.6 Hydraulic Evaluation

Several tools are available for hydraulic evaluation. Information on residence time, heterogeneities in flow rate, and long-term changes in flow rate can be evaluated with these techniques. Slug tests may be used to determine media flow characteristics within and around the permeable reactive barrier. These tests can provide information on hydraulic conductivity within various media. Caution should be employed in and around the ISTZ, where the test could change the residence time within the reactive media. In-situ flow meters or groundwater velocity probes are also available for the determination of flow rates. These field instruments can provide real-time data on the permeable reactive barrier without affecting residence time. Tracer tests may also be utilized to provide information on flow rate through the ISTZ. Whether a permit is required for the injection of the tracer material will be a state-specific determination.

6.7 Long-Term Monitoring

One of the benefits of using a permeable reactive barrier is the potential for substantial reduction in monitoring requirements in relation to those of other remedial systems (e.g., pump and treat). A reduction in the quarterly monitoring for field parameters and organic and inorganic constituents and in monthly hydraulic monitoring can be instituted once the performance of the permeable reactive barrier is documented over an extended period. Evaluation should occur on a yearly basis to determine the adequacy of monitoring frequencies and locations.

6.8 Examples of Monitoring Scenarios

Figures 2 and 3 are provided to graphically depict monitoring issues discussed in this document. Expected groundwater flow lines are shown on each diagram. The purpose of the drawings is to provide hypothetical examples of monitoring well placement. Site-specific conditions should always dictate the placement of monitoring wells.

Appendix B also provides monitoring scenarios from a permeable reactive barrier that has been installed as a treatment system. These figures provide examples of how systems are monitored in real applications. Again, site-specific conditions should always dictate the placement of monitoring wells.

6.8.1 Rationale behind Monitoring Well Placement

The following key pertains to the monitoring scenarios illustrated in Figures 6-1 and 6-2 on pages 21 and 22:

A Monitoring well placement to determine downgradient groundwater quality by sampling organic parameters.

B Monitoring well placement to ensure treatment and determine groundwater flow rate by sampling field, inorganic, and organic parameters.

C Monitoring well placement to determine treatment, groundwater flow rate, and precipitate formation through field, inorganic, and organic parameters. Note wells B, C, and D are located

along lines through the ISTZ to monitor flow paths. Monitoring wells are placed at both the sides and the middle of the ISTZ to monitor differences in flow.

D Monitoring well placement to determine upgradient concentration of contaminants, precipitation formation, and groundwater flow rate through field, inorganic, and organic parameters.

E Monitoring well placement to determine breakthrough, underflow, or overflow across the funnel wall through field and organic parameters.

F Monitoring well placement to ensure plume capture and determine whether contaminant is migrating around the funnel wall through field and organic parameters.

Figure 6-1 Funnel-and-Gate Monitoring Diagram

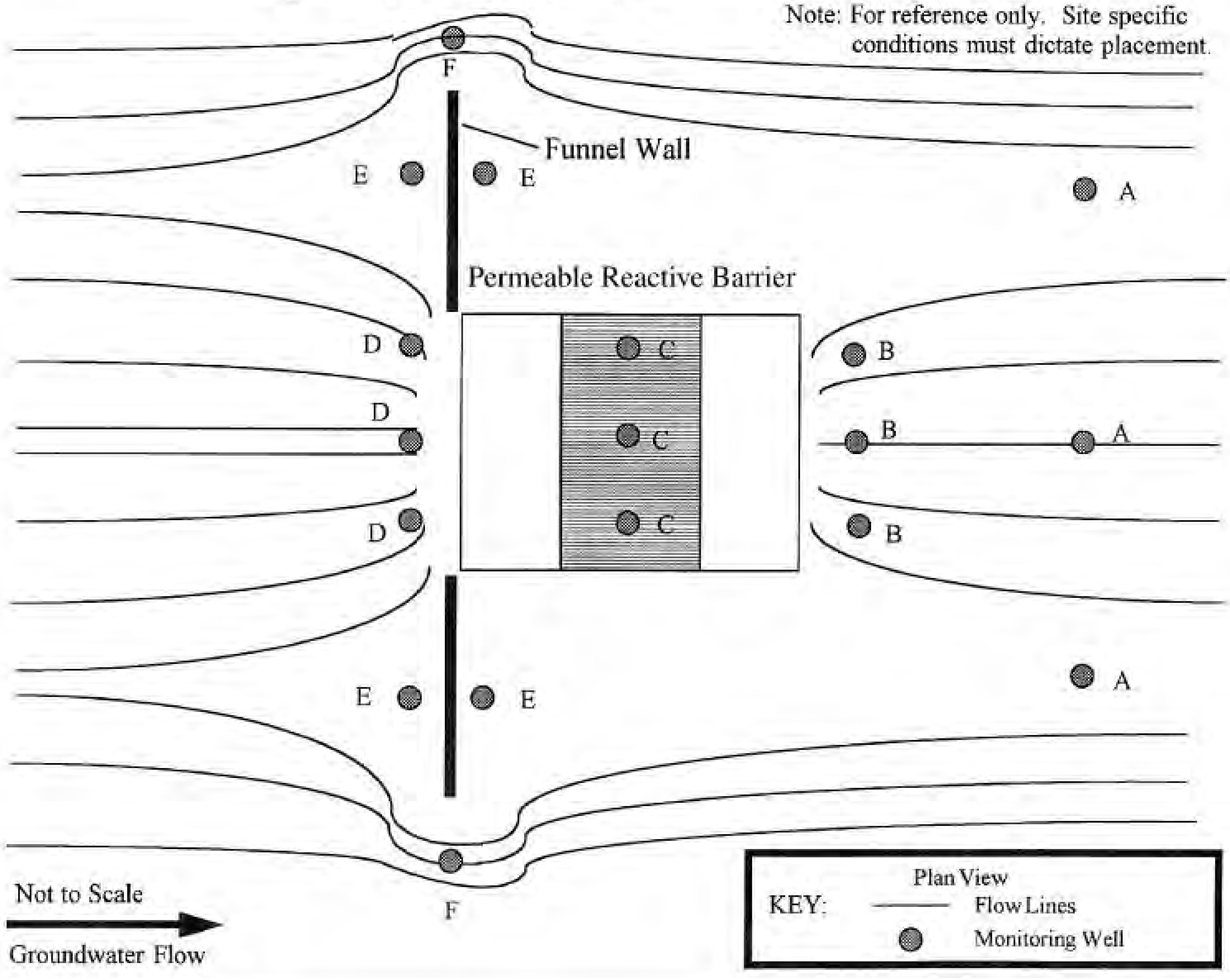
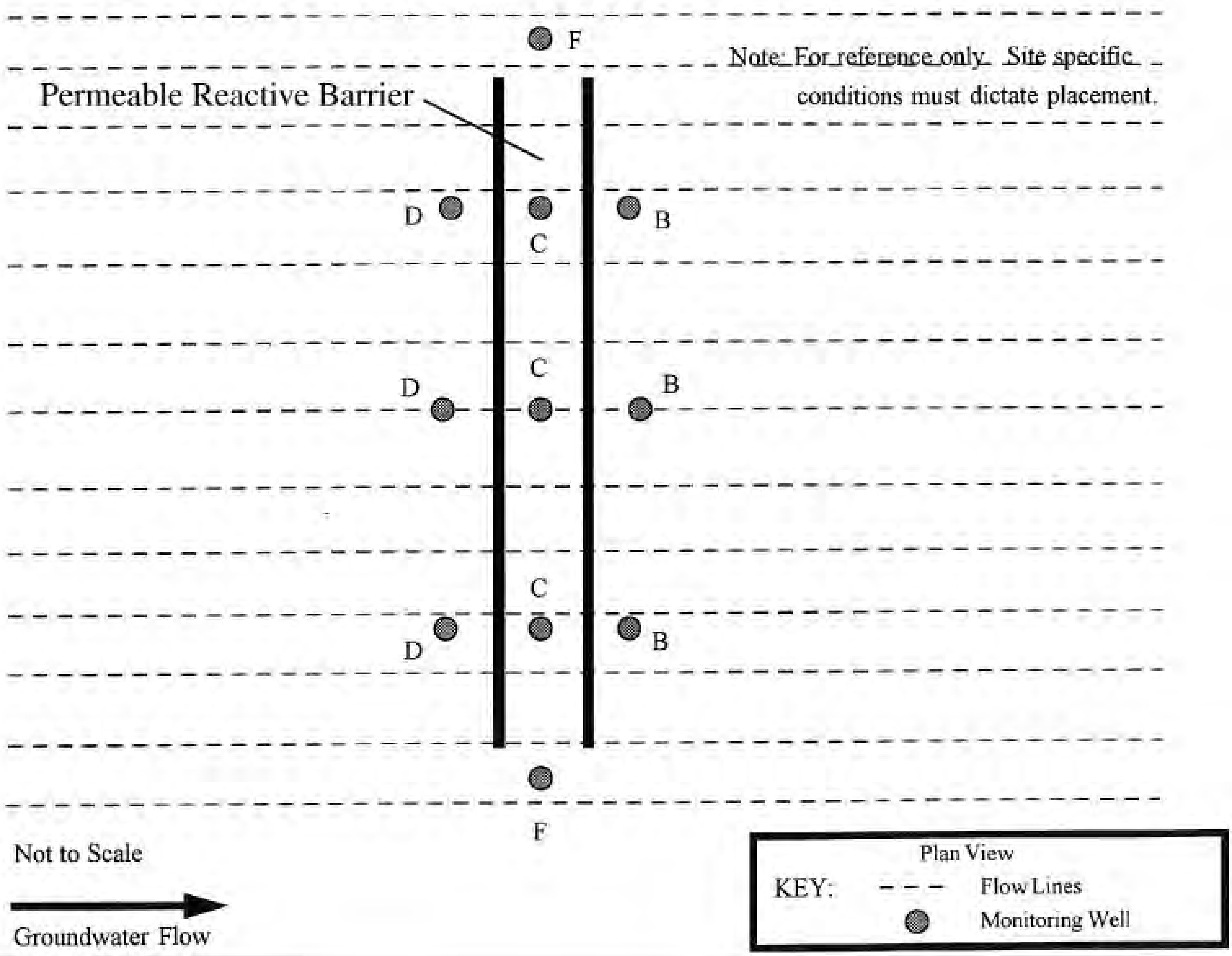


Figure 6-2 Continuous Permeable Reactive Barrier Monitoring Diagram



7.0 DISPOSAL OF WASTES DURING BARRIER PLACEMENT

Contaminated soils may be generated during installation. Any contaminated soil should be classified in accordance with state and federal Hazardous Waste Regulations prior to disposal. The classification of the soil will determine the disposal method. Classification can occur in situ through the use of soil borings and waste classification sampling prior to removal of the soil from the installation site. An alternative is to stockpile the soil on site during installation and collect classification samples prior to disposal. In either situation, state-specific requirements should be followed for sample parameters and frequency to ensure the soil is properly classified prior to disposal. In cases where the generated soil is classified as hazardous, state and/or federal regulations will dictate the disposal method. Land Disposal Restrictions and listed hazardous waste requirements should be adhered to where applicable. State-specific requirements may also regulate the disposal of nonhazardous waste if the material is contaminated.

Contaminated groundwater may be generated from the dewatering of the excavation during the installation process. Any contaminated water shall be disposed of in accordance with state-specific requirements. Several options may apply; water can be disposed of at a permitted off-site commercial facility, a publicly owned treatment works, or on site in accordance with a NPDES permit. The use of continuous trencher or jetting installation techniques can often reduce the total volume of contaminated soil and groundwater requiring treatment/disposal.

8.0 MAINTENANCE AND CLOSURE CRITERIA

The long-term maintenance and closure requirements for permeable reactive barriers are not well defined because the technology has only recently been employed full scale. One concern is the loss of hydraulic conductivity (clogging) over time. Standard monitoring of field parameters and inorganic constituents along with groundwater elevation data can provide an indication of loss of permeability within the barrier. If the performance of the permeable reactive barrier is affected by loss of permeability or routine monitoring indicates a potential problem, monitoring frequency of all parameters should be increased to identify the effects on groundwater contaminant concentrations and hydraulics.

If the loss of conductivity is severe, special monitoring considerations such as coring of the reactive media can be employed to better understand the problem. Coring of the media is not a technique that should be employed on a regular basis. It may, however, play a role in determining the source and extent of clogging. Core samples should be obtained from the top several inches of the middle of the media and from the bottom of the media, being careful not to allow oxygen to come in contact with the cores prior to analysis. The number of locations to sample will depend on the size of the ISTZ. Boreholes should be backfilled with fresh media. Various microscopic imaging techniques are available to determine the presence of precipitates. These include scanning electron microscopy, energy dispersive x-ray spectroscopy, and powder x-ray diffractometry.

Maintenance issues of regulatory concern involve the regeneration of the reactive media and the restoration of the hydraulic permeability of the permeable reactive barrier. If the barrier is being repaired or reconstructed, contaminated reactive media or soil may be generated. Any material

generated should be properly classified and disposed of in accordance with state and federal Hazardous Waste Regulations. Another mechanism to reestablish the reactivity of the media and/or the barrier permeability could involve a reagent flush. The use of reagents (i.e., acid solutions) to rejuvenate the permeable reactive barrier is currently under investigation. A flushing procedure may require a permit, careful monitoring, and a contaminated groundwater extraction process. State-specific requirements will dictate where and how reagents can be introduced. Any flushing procedure should be reviewed on a case-specific basis to ensure proper regulatory controls.

Closure of a permeable reactive barrier will typically not occur until the upgradient and downgradient aquifer meets the applicable groundwater quality standards or cleanup goals. As a result, permeable reactive barriers will often remain active for an extended period of time. Upon closure, there would usually be no need to remove the permeable reactive barrier; in a few circumstances, state-specific requirements may dictate removal. One such scenario involves the clogging of the barrier over time, forming an impermeable barrier that may affect groundwater flow conditions. In cases where the permeable reactive barrier will remain in place after closure, concern may arise regarding the long-term solubility of the reactive media and its effect on downgradient water quality. Dissolved iron or other elements from the barrier could possibly impact water quality. The need for postclosure downgradient monitoring of iron or other reactive media components should be based on the inorganic data collected during operation of the permeable reactive barrier. Depending on the concentration of inorganic parameters detected during operation of the permeable reactive barrier, consideration may be given to reducing or eliminating future monitoring. Any reduction should be based on a thorough understanding of the dynamics of the system. In addition, consideration should be given to the proper decommissioning of those monitoring wells that will no longer be needed or used.

9.0 HEALTH AND SAFETY

A site-specific Health and Safety Plan should be developed and implemented in accordance with the Occupation Safety and Health Administration (OSHA) regulations 20 CFR 1910.120, the Hazardous Waste Operations and Emergency Response Rule. The Plan should address the following issues:

Key Personnel	Site Control
Health and Safety Risks	Decontamination
Training	Emergency Response
Protective Equipment	Confined Space Entry
Medical Surveillance	Underground Utility Mark-out
Spill Containment	Trench Entry
Air Monitoring	Accident Procedures

10.0 STAKEHOLDER CONCERNS

A stakeholder is any nonregulatory affiliated party with interest in a particular site or technology. Stakeholders within the community in which the permeable reactive barrier will be deployed should be properly informed, educated, and involved in the decision making process and consulted regarding the utilization of the technology. This may require holding public meetings or information sessions, distributing informative bulletins, or developing a neighborhood-canvassing program. The document entitled "A Guide to Tribal and Community Involvement in Innovative Technology Assessment" explains the need for community involvement during site planning and implementation and should be used as a reference tool in forming a community outreach program. The EPA has developed a citizen's guide entitled "A Citizen's Guide to Treatment Walls," which can be ordered directly from EPA.

Stakeholders close to the installation of a permeable reactive barrier may have the following concerns:
- truck traffic,
- noise,
- heavy equipment operation,
- work hours,
- off-site excursion of dust,
- off-site excursion of organic compounds,
- proper site control and access restrictions,
- potable well contamination,
- groundwater quality data,
- effectiveness,
- contingency remedial plans.

11.0 VARIANCES

As this technology develops, innovation in sampling and analytical methods may result in proposals to utilize alternative methods. Methods other than those outlined in this guidance may be proposed as a variance. State regulatory agencies should evaluate the applicability of a variance based upon the following criteria:

- The method has previously been used successfully under similar site conditions, as documented by a regulatory agency.
- The method has been tested successfully by an independent, nonregulatory verification entity.
- The method is approved by the agency, based upon site-specific conditions or technology modifications.

12.0 REFERENCES

"Citizen's Guide to Treatment Walls," U.S. Environmental Protection Agency, Technology Innovation Office, EPA 542-F-96-016, Sep. 1996.

Commonwealth of Massachusetts, Department of Environmental Protection, "Standard References for Monitoring Wells," WSC-310-91, 1991.

"Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents," prepared for Armstrong Laboratory/Environics Directorate by Battelle, Feb. 1997.

"Discrete-Level Ground-Water Monitoring System for Containment and Remedial Performance Assessment Objectives," Bob Puls, J. Environ. Engineering, June 1996.

"Draft Design Protocol for Permeable Barriers To Remediate Chlorinated Solvents," prepared for Armstrong Laboratory/Environics Directorate (AL/EQ) by Arun Gavaskar et al., Nov. 1996.

"Performance Monitoring Plan for a Pilot-Scale Permeable Barrier at Moffett Federal Airfield," prepared for Naval Facilities Engineering Service Center, Port Hueneme, CA by Battelle, Dec. 1996.

"Final Report Remedial Implementation Interim Corrective Measure Containment System," Federal Highway Administration, Denver Federal Center, prepared for USACE by IT Corp., July 1996.

"Guide to Documenting Cost and Performance for Remediation Projects," member agencies of the Federal Remediation Technology Roundtable, EPA-542-B-95-002, Mar. 1995.

"In Situ Remediation Technology Status Report: Treatment Walls," U.S. Environmental Protection Agency, Technology Innovation Office, EPA-542-K-94-004, April 1995.

"Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures," Bob Puls and Michael Barcelona, USEPA Ground Water Issue, April 1996, EPA/540/S-95/504.

"Research on Permeable Barriers," Stan Morrison and Robert Spanger, Rust Geotech for the RTDF Permeable Barrier Walls Working Group, Nov. 1995.

"Second Quarter Monitoring Results, 1997 Interim Groundwater Remediation Measure Denver Federal Center," prepared for Federal Highway Administration by US Geological Survey, Sep. 1996.

"Technology Evaluation Report: Treatment Walls," prepared for Groundwater Remediation Technologies Analysis Center, Pittsburgh, PA by University of Pittsburgh, Oct. 1996.

APPENDICES

APPENDIX A

Acronyms and Abbreviations

2-D	2-dimensional
3-D	3-dimensional
Ba	barium
^{o}C	degrees Celsius
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Cl	chlorine
CFR	Code of Federal Regulations
Al	aluminum
Br	bromine
Ca	calcium
CS	chlorinated solvents
d	days
DCE	dichloroethylene
DO	dissolved oxygen
DOC	dissolved organic carbon
Eh	redox potential
EPA	Environmental Protection Agency
Fe	iron
F	flourine
GC/MS	gas chromatograph / mass spectrometry
h	hours
HNO_3	nitric acid
H_2SO_4	sulfuric acid
ISTZ	in-situ treatment zone
ITRC	Interstate Technology and Regulatory Cooperation Work Group
K	potassium
Mg	magnesium
mg/l	milligrams/liter
mL	milliliter
Mn	manganese
Na	sodium
NO_3	nitrate
NPDES	National Pollution Discharge Elimination System
NSF	National Sanitation Foundation
OSHA	Occupational Safety and Health Administration
PCE	tetrachloroethylene, perchloroethylene
ppb	parts per billion
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control

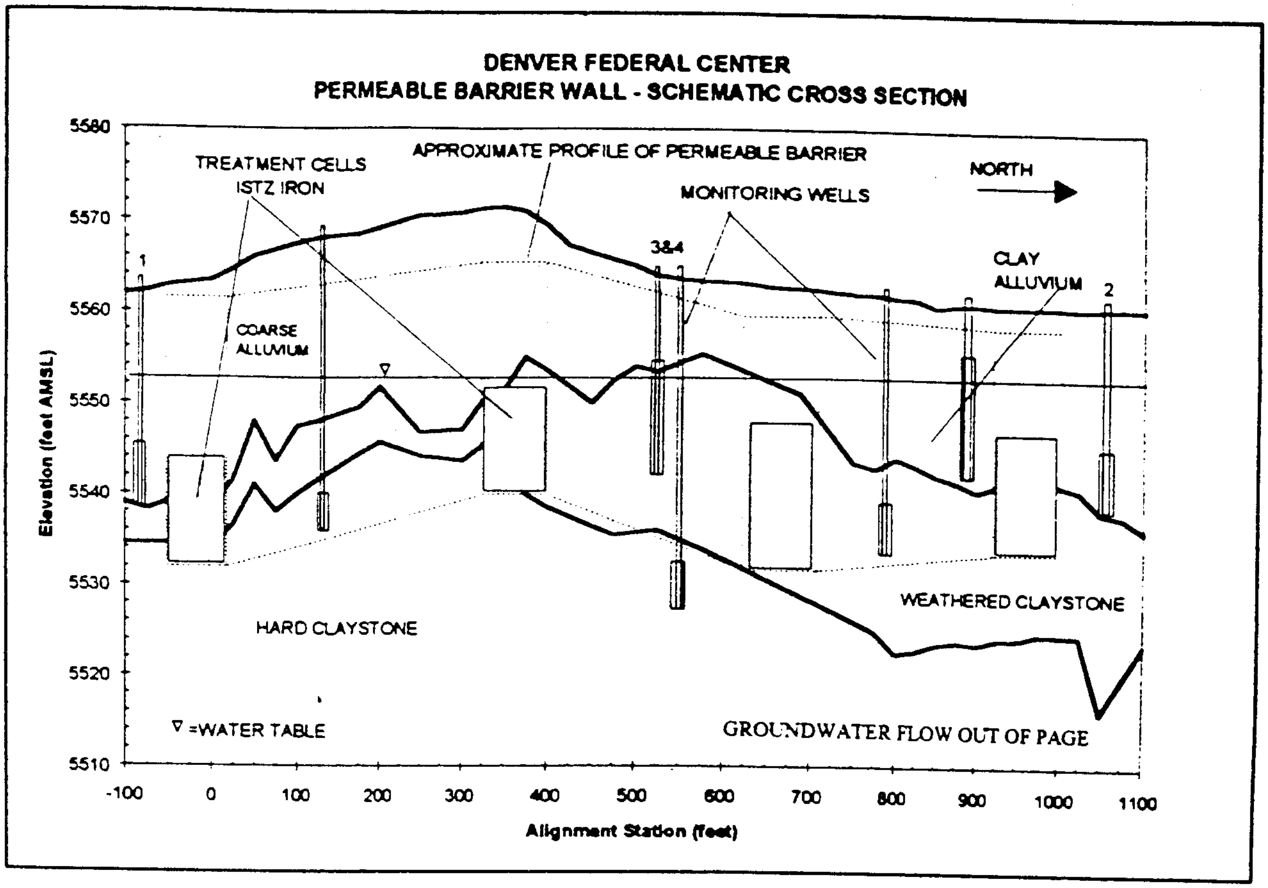
RCRA	Resource Conservation and Recovery Act
SO_4	sulfate
TBD	to be determined
TCE	trichloroethene, trichloroethylene
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
VOA	volatile organic analyte
UIC	underground injection control
VOC	volatile organic compound

APPENDIX B

Denver Federal Center Permeable Barrier

Denver Federal Center Permeable Barrier

Schematic Cross Section



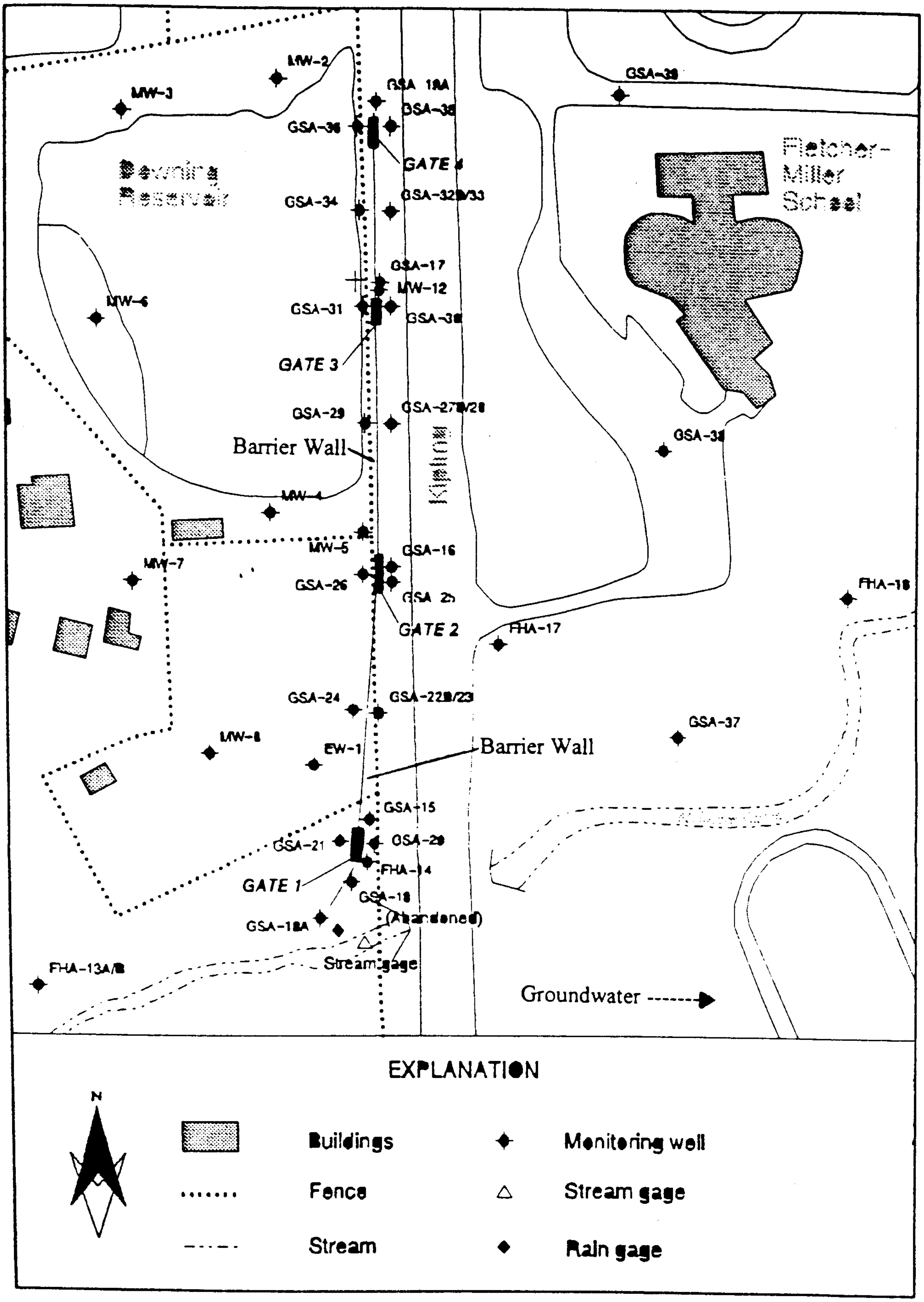
The diagram above conceptually illustrates in cross section, the groundwater monitoring system for the Denver Federal Center (DFC) funnel-and-gate system. The aquifer at DFC consists of three lithologic units of decreasing permeability with depth: alluvium, weathered claystone, and hard claystone.

To achieve maximum containment, the base of the containment system should be keyed into the unit with the lowest permeability (at DFC, this would be the hard claystone). However, at the north end of the DFC system, it was not technically feasible to drive sheet piling to this horizon (a depth greater than 45 feet). This situation is mitigated by a decrease in transmissivity in the alluvium to the north, as it transitions from sand and silt south of the weathered claystone high, to clay north of the high.

Ideally, monitoring wells should be installed to monitor groundwater levels and chemistry at strategic locations in each unit. Wells, numbered 1 and 2 on the diagram, are located to monitor for by-pass at either end of the permeable reactive barrier (these would correspond to GSA-18a and 19a on the site map).

Twin monitoring wells, screened to monitor vertical gradients between the alluvium and the underlying confining layers, were located at points midway between the treatment cells and are represented by wells on the diagram numbered 3 and 4 (these would correspond to well pairs GSA-23, 22D; GSA-28, 27D; GSA-33, 32D on the site map).

Wells located in the treatment cells (the permeable sections of the barrier containing zero-valent iron) are not represented on this schematic.


MW-2
MW-3
GSA-39
GSA 19A
GSA-35
GSA-36
GATE 4
Fletcher-Miller School
GSA-34
GSA-32B/33
GSA-17
MW-12
MW-6
GSA-31
GSA-30
GATE 3
GSA-29
GSA-27B/28
Barrier Wall
GSA-38
MW-4
MW-5
GSA-16
MW-7
GSA-26
GSA 25
GATE 2
FHA-18
FHA-17
GSA-24
GSA-22B/23
GSA-37
MW-8
EW-1
Barrier Wall
GSA-15
GSA-21
GSA-20
FHA-14
GATE 1
GSA-19
GSA-19A
(Abandoned)
Stream gage
FHA-13A/B
Groundwater
EXPLANATION
N
Buildings
Fence
Stream
Monitoring well
Stream gage
Rain gage

APPENDIX C

ITRC Contacts, ITRC Fact Sheet, ITRC Product List, and Document Evaluation Survey

ITRC Permeable Reactive Barriers Team
Project Contacts

Matt Turner
PRB Team Leader
New Jersey Dept. of Environmental Protection
401 E. State Street, 5th Floor
Trenton, NJ 08625
P 609-984-1742
F 609-633-1454
mturner@dep.state.nj.us

Peter Strauss
Stakeholder Representative
PM Strauss and Associates
317 Rutledge Street
San Francisco, CA 94110
P 415-647-4404
F 415-824-1072
pstrauss@igc.apc.org

Dan Sogorka
PBW Team Project Support
Remedial Technologies, LLC
11417 Sunset Hills Road, Suite 230
Reston, VA 20190
P 703-481-9095
F 703-481-9125
dsogorka@remedial.com